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IGNITION OF NOS 365 LIQUID PROPELLANT CONTAINING AN AIR BUBBLE UNDER SIMULATED BREECH PRESSURIZATION CONDITIONS

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A setback simulator has been used to generate pressure within a liquid propellant (NOS 365) containing a suspended air bubble. The bubble volume was varied from 1 to 200 μliters. Several tests were made using a 1000 μliter air space above the liquid propellant. The maximum test pressure was around 600 MPa and the pressurization rates ranged from 25 MPa/msec to 800 MPa/msec. The following conclusions were reached:

(continued)

1. A suspended air bubble makes liquid propellant more sensitive to pressure ignition.

2. The intensity of the reaction appears to increase with bubble size.

3. Higher pressurization rates caused ignition of neat liquid propellant. However, this may be due to extrusion of the propellant around the pistons.

4. The impact mode of activator operation, although permitting higher pressures and pressurization rates than the contact mode, also gives more variability in the results.

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I. INTRODUCTION

The proposed use of liquid propellant* in large caliber guns makes it necessary to understand those factors which may cause erratic propellant performance. In the work reported here we have investigated the sensitizing effect of a single air bubble suspended in liquid propellant and compressed to pressures as high as 600 MPa at rates from approximately 25 MPa/msec to 800 MPa/msec. The propellant tested was NOS 365 (hydroxyl ammonium nitrate, alkyl amine nitrate) and the bubble volume ranged from 1 to 200 μliters. Several firings were made using an air space (ullage) immediately above the propellant instead of a suspended bubble.

II. EXPERIMENTAL

A. ACTIVATOR DESCRIPTION

In order to simulate the breech pressurization of an LP gun firing, we used a setback simulator (activator) built at BRL. This device was based on a design which had been used at Picatinny Arsenal for many years. Improvements in tolerance and design were made by Mr. B. C. Taylor, recently retired from BRL[1]. The activator was turned to a vertical position to facilitate the use of LP with a suspended bubble. A schematic drawing of activator operation is shown in Figure 1.

A mixture of black powder and PETN is ignited by an electric match. The combustion products are contained within the breech housing and push against the large (76.2mm diameter) breech piston which is free to move. The pressure on the breech piston is transmitted to a sample by means of a thrust coupler, a steel insert and a smaller diameter hardened steel coupling piston. The pressure produced in the sample is the breech pressure multiplied by the ratio of breech piston area to coupling piston area. The sample is held within a mild steel confinement cylinder 63.5mm diameter x 63.5mm length. The sample butts against a manganin pressure gauge which is cemented to a gauge block. An adjustable screw supports this assembly. In the contact mode of activator operation, just described, the peak pressure and pressurization rate are controlled by the peak pressure and burning rate of the propellant mixture.

The activator can also be used in the impact mode as illustrated in Figure 2. Shear pins 3.175mm diameter are inserted through the breech housing and into the breech piston in order to restrain its motion until the pressure increases to around 2.33 MPa causing the pins to shear. The large piston, pushed by the high pressure gases, is accelerated as it moves across a selected air gap. The peak pressure and pressurization rate at impact are controlled by the piston velocity (air gap length) and

*Liquid propellant will be referred to as LP for brevity.

[1] *Taylor, Boyd C. and Ervin, Lewis H., "Mode of Ignition in the Picatinny Arsenal Activator (Artillery Setback Simulator)," Proceedings of the Conference on the Standardization of Safety and Performance Tests for Energetic Materials, Volume I, Sep 77, ARRADCOM, Dover, NJ, Special Publication ARLCD-SP-77004*

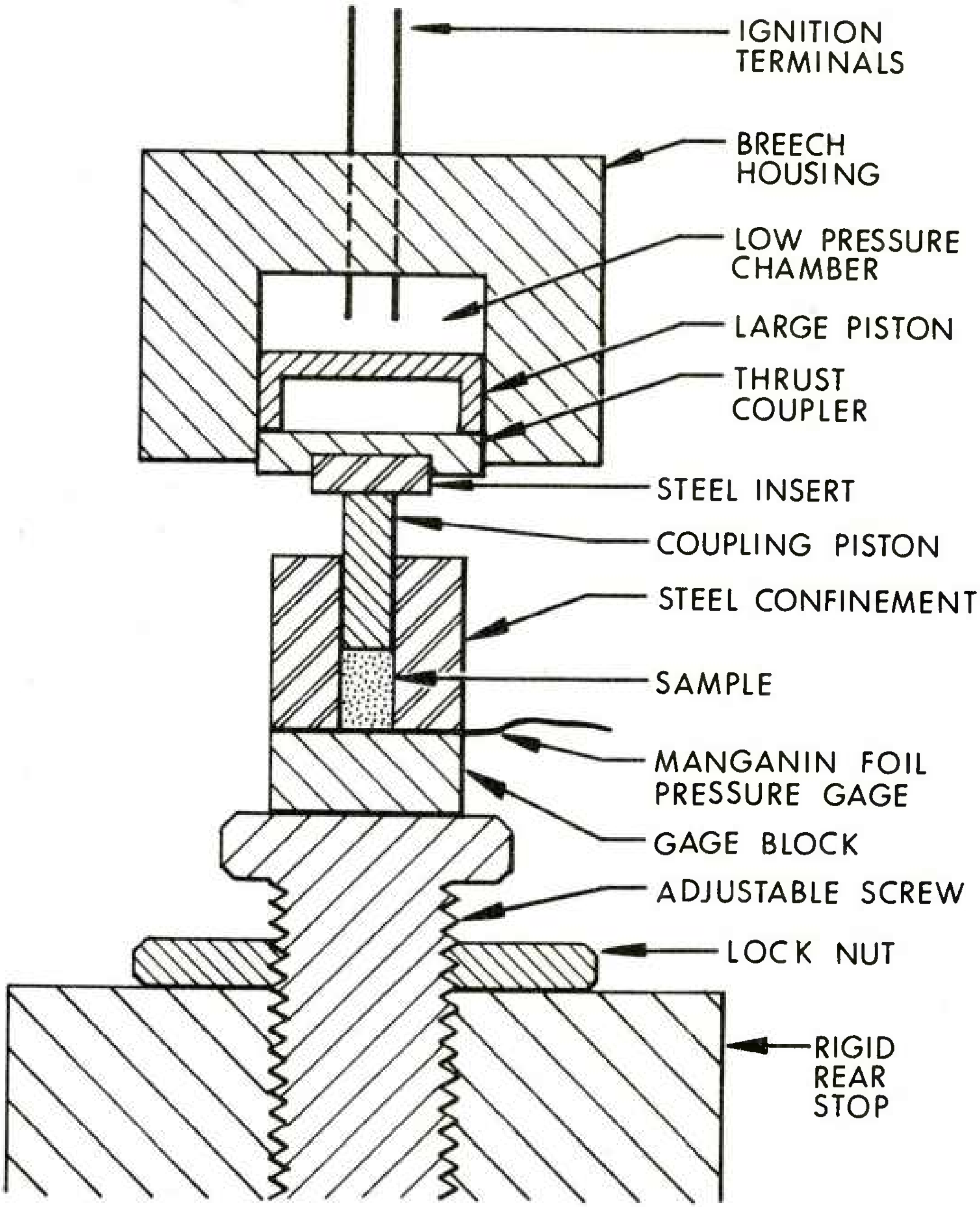


Figure 1. Activator configuration for contact mode pressurization of the test sample.

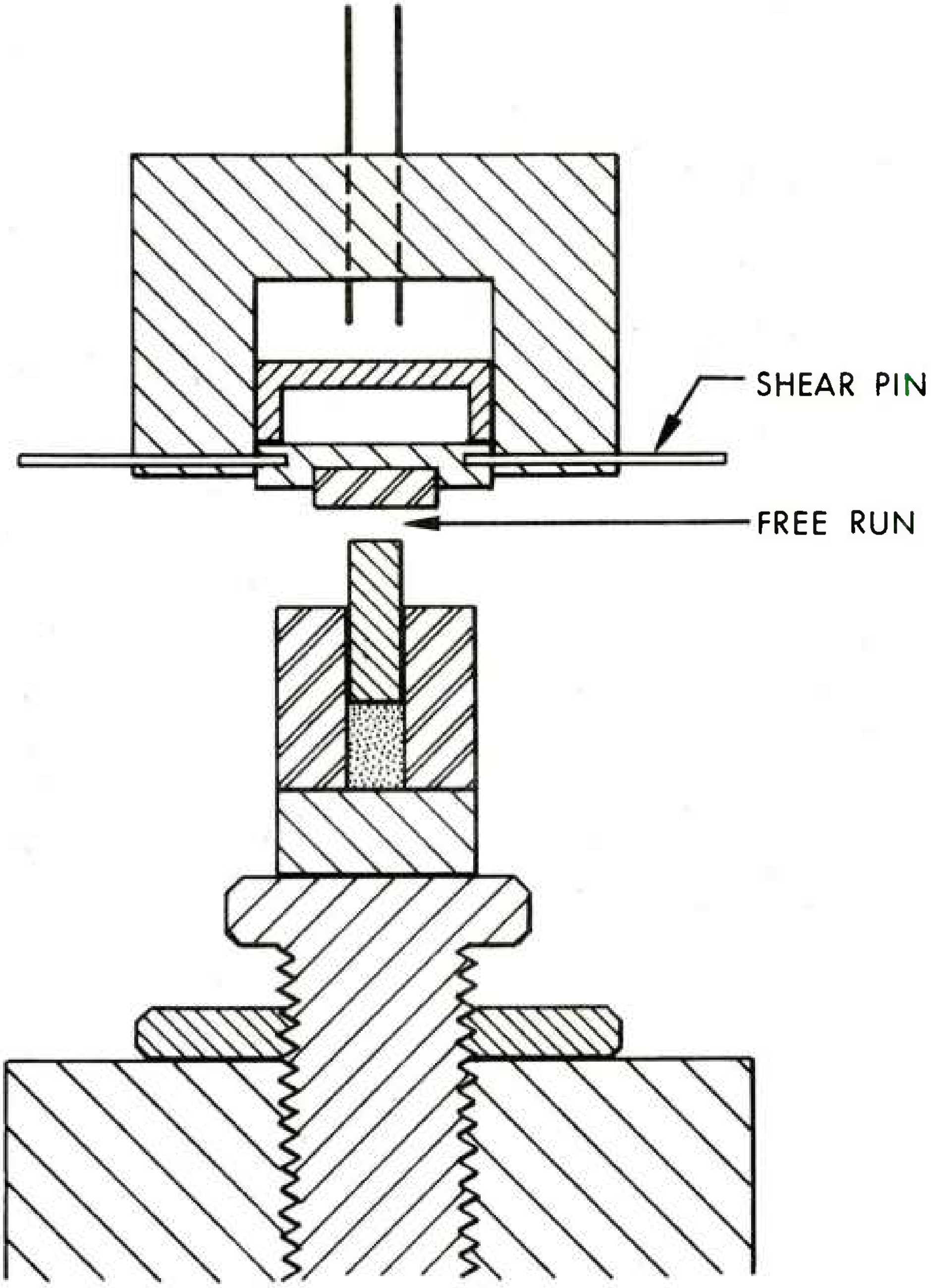


Figure 2. Activator configuration for impact mode pressurization of the test sample.

rigidity of the piston and sample train elements. In the impact mode there are usually several impact pressure pulses of decreasing amplitude as the piston rebounds and strikes again. In both the impact and contact modes the final pressure is determined by the breech pressure and slowly decreases over an interval of seconds as the propelling gases cool. Typical pressure pulses for the contact and impact modes are shown in Figure 3.

B. BUBBLES SUSPENDED WITHIN PLASTIC CELLS

In the first series of tests it was decided to suspend the air bubble within a plastic cell filled with liquid propellant. This was done to facilitate bubble implacement. The cell design is illustrated in Figure 4. A nylon net was formed into a concave shape and cemented inside the cell as shown. The cell was filled with liquid propellant and, using a calibrated syringe, an air bubble of known volume was injected below the net. A plug with a 1.17mm diameter hole and a beveled underside was cemented to the cell using dichlorethylene solvent. Any extraneous air bubbles were, at this time, removed by tapping the cell and allowing them to escape to the atmosphere. Finally a cap was cemented over the plug. Overall cell dimensions were 19.05mm diameter x 25.4mm length with 3.175mm thick walls. We hoped that the 12.7mm diameter piston would shear the plug at top of the cell and apply pressure to the 12.7mm diameter liquid column, but this concept did not work, as we shall see below. The cell contained approximately 2cc of liquid propellant.

The plastic cell containing propellant and a suspended air bubble was loaded into a steel confinement cylinder and placed in the activator as illustrated in Figure 5. In this configuration, using a 12.7mm diameter coupling piston and a 19.05mm diameter bore to accommodate the cell, the hydrostatic pressure generated in the test sample produces a net force which would move the confinement cylinder in the upward direction if it were not restrained by the steel restraining plate shown.

III. RESULTS

A. PROPELLANT CONTAINED WITHIN PLASTIC CELLS

1. CONTACT MODE.

In the contact mode illustrated in Figure 5 the pressure reaches a maximum value in about 5 msec. The maximum pressure on the test sample is determined by the breech powder loading and the face area of the coupling piston and is about 500 MPa in these experiments. The results are shown in Table 1.

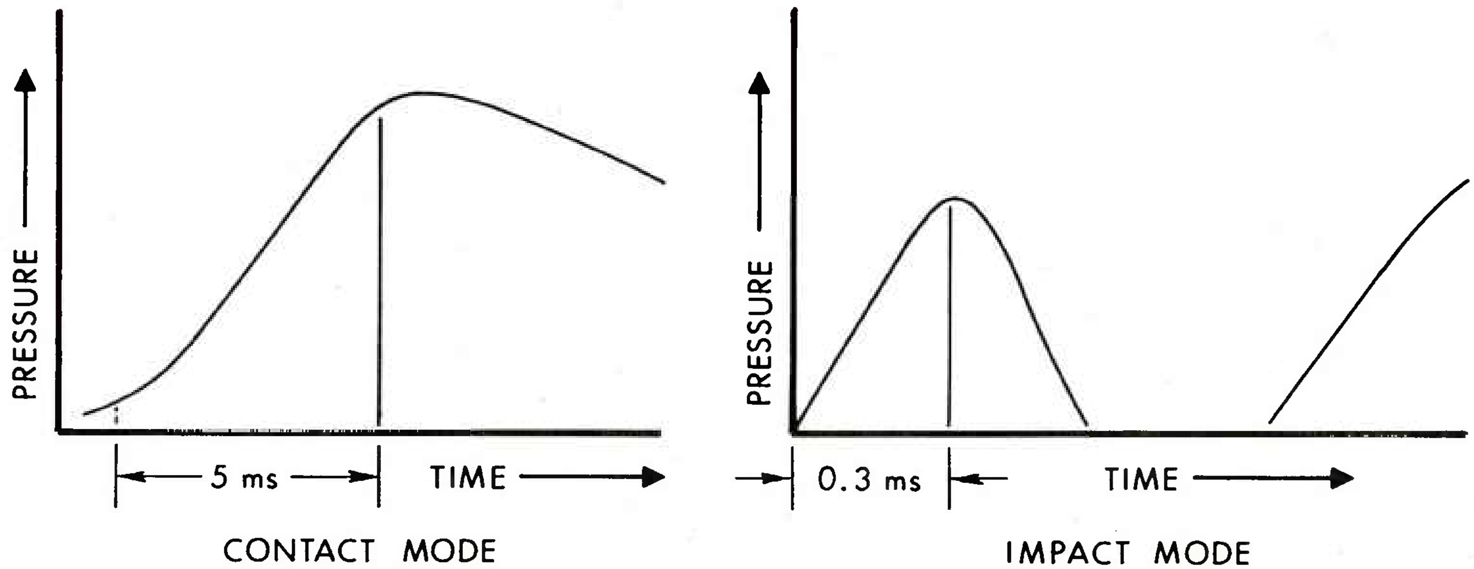


Figure 3. Typical pressure pulses obtained when the activator is used in either the contact or impact mode.

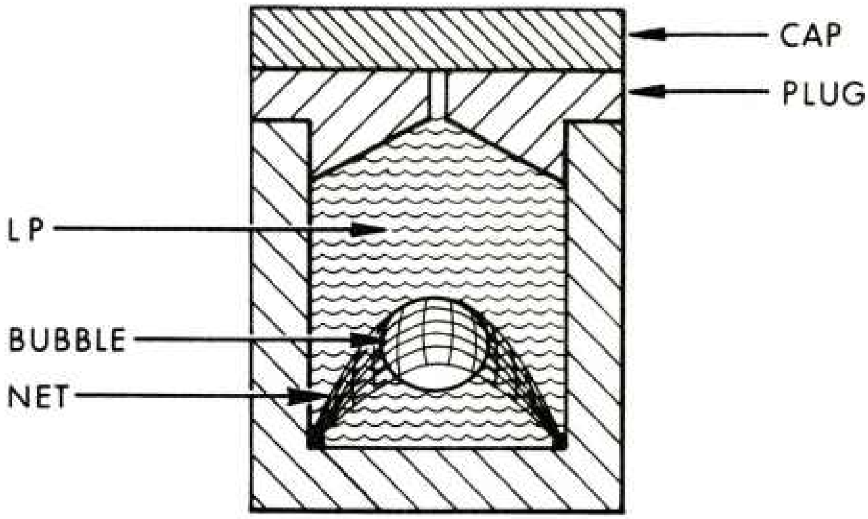


Figure 4. Plastic cell containing LP and a suspended air bubble.

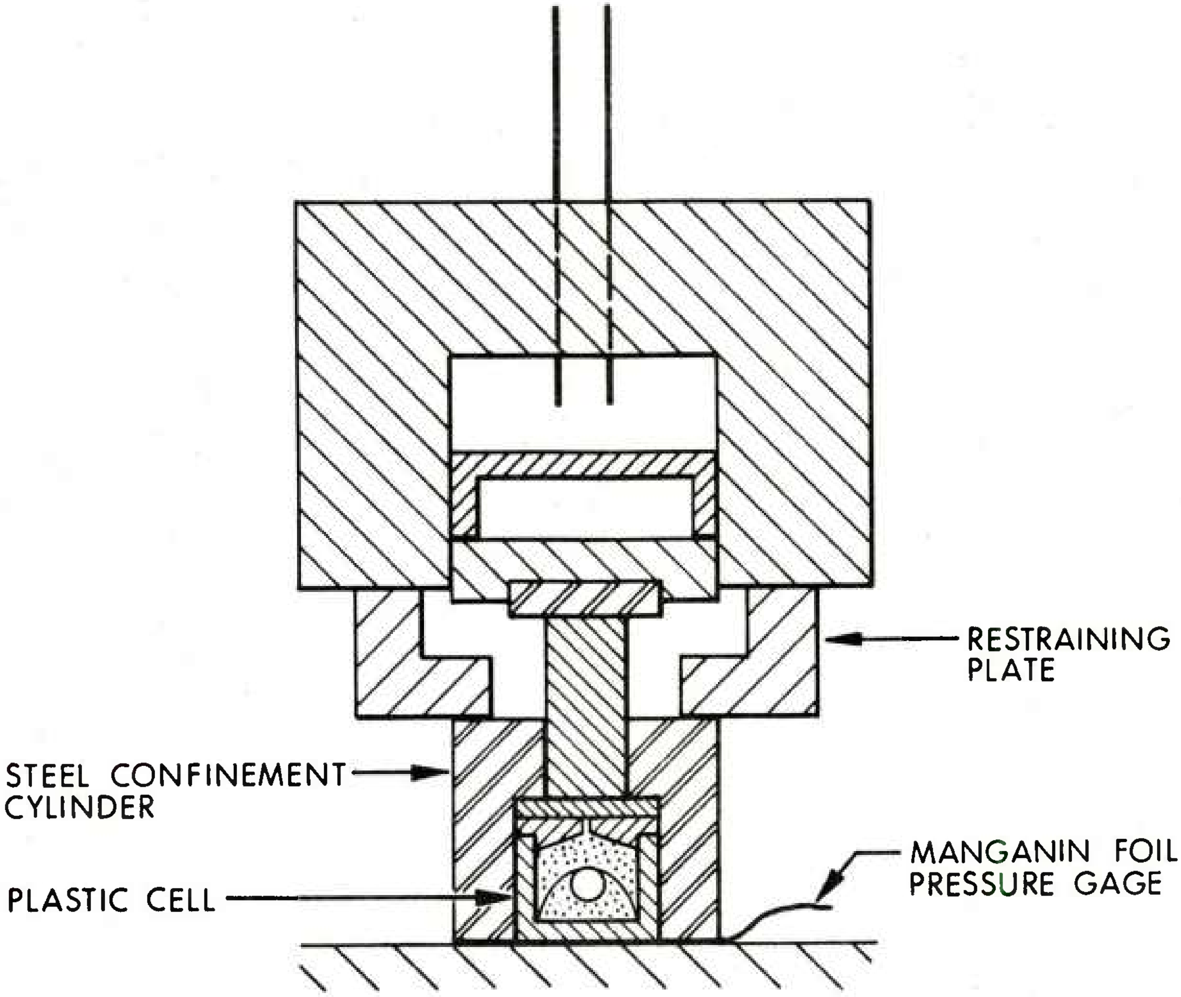


Figure 5. Activator configuration for LP contained in a plastic cell. A restraining plate is used to prevent upward motion of the steel confinement cylinder. Contact mode of operation is illustrated here.

TABLE I

Shot #	Nominal Risetime (msec)	Peak Pressure (MPa)	Bubble Vol. (μℓ)	Results*
1	5	530	0	0
2	5	530	0.5	0
3	5	530	0.06	1
4	5	530	4.2	2,3
5	5	210	1000 (air gap)	2,3

* 0 = no reaction, LP recovered
  1 = mild burning
  2 = more severe burning, inner wall of cell blackened
  3 = foam structure evident on inner cell walls
  4 = loud bang

2. IMPACT MODE.

In the impact mode, the peak pressure increases with free run. The rise time is a function of the stiffness of the test sample and supporting elements. It is nominally 0.3 msec in the tests reported here, although, as will be explained in the section immediately following, the rise time was perturbed by the plastic cell. The results are shown in Table II.

TABLE II

Shot #	Nominal Risetime (msec)	Peak Pressure (MPa)	Bubble Size (μℓ)	Results*
6	0.3	600	0.1	2,3
7	0.3	600	1.8	2
8	0.3	600	100	4
9		377	1000 (air gap)	1,3

* 0 = no reaction, LP recovered
  1 = mild burning
  2 = more severe burning, inner wall of cell blackened
  3 = foam structure evident on inner cell walls
  4 = loud bang

3. DISCUSSION OF PLASTIC CELL RESULTS.

When it was decided to use plastic cells to contain our propellant samples, it was not anticipated that the structural strength of the cells under compression would have an effect on the pressurization rate of the air bubbles suspended within the propellant. However, in later experiments, when a manganin foil pressure gauge was positioned directly under the sample cell as shown in Figure 5, it became evident that the normal activator pressure pulse was being perturbed by the plastic cell. We attribute this perturbation

to the structural strength of the cell resisting collapse. The top of the cell did not shear, as was planned, but instead the whole cell compressed longitudinally and the walls thickened. Figure 6A shows the pressure recorded close to the cell when the activator is used in the impact mode with a free run of 12.7mm and a coupling piston diameter of 19.0mm. The cell is half full of LP with a 1000 μℓ air space above it. This impact pressure pulse shows a leading low pressure region (36 MPa) lasting 0.25 msec increasing to 400 MPa after an additional 0.26 msec. This shot (number 9 in Table II) gave results which were unexpectedly mild considering the high pressure and large air volume involved. The walls of the cell had increased in thickness from 3.2 to 5mm. A similar shot was fired using water instead of LP in the cell; in this case the recovered cell still had all the water in it and the wall thickness had increased to only 4.2mm. The difference in final wall thickness between these two shots is attributed to ignition of the LP. The burning LP would soften the plastic and, in addition, as the gaseous products vent the cell would collapse still further. The pressure gauge record for the water-containing cell is shown in Figure 6B.

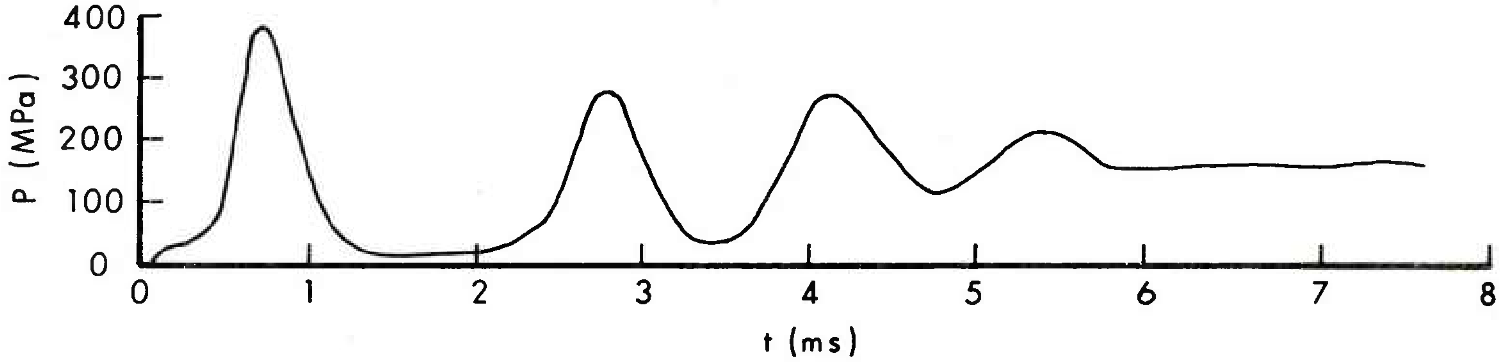
Because the plastic cell made interpretation of the data more difficult we decided to abandon this approach. However, referring to the results in Tables I and II, there appears to be an increase of propellant reaction with bubble size.

B. LP CONTAINED BY SEALING PLUGS

Since the plastic cell complicated interpretation of our results we decided to eliminate it and use Plexiglas plugs to seal the LP within the steel confinement cylinder. This arrangement is shown in Figure 7. In order to assemble the LP sample within the steel confinement the following procedure was followed. The plastic plugs were machined 0.064 mm larger than the bore diameter and then placed in liquid nitrogen in order to shrink them. The base plug was then inserted into the bore, flush with the lower surface of the confinement cylinder and allowed to expand, thereby forming a tight seal. A hemispherical nylon net, glued to a plastic ring as shown in Figure 7, was slid into place on the base plug. (The net had been shaped by stretching nylon mesh over a hemispherical form, gluing the plastic ring to it and then lightly spraying it with Krylon* crystal clear spray number 1302 to increase its structural strength.) Next, the LP was slowly syringed into the bore, in order to avoid bubble creation, until the net assembly was completely submerged and the desired amount of LP was in place. The top plug was then taken from the liquid nitrogen and inserted into the steel confinement bore to the proper level and allowed to expand in place. Next, an air bubble was injected inside the net by inserting a calibrated, air-tight syringe through the screw hole and under the net; also, at this time, additional LP was added in order to fill the screw hole volume. Next, the top plug was sealed by a nylon screw which expelled excess LP. A rubber washer or silicone sealant was used around the screw head area to fill any gaps. The top plug surface was wiped dry and the assembly was inspected for extraneous air bubbles by looking through the transparent end plugs. Since the nylon net

*Krylon no. 1302 is a protective spray coating containing toluene. It is manufactured by the Borden Company.

(B.)



(A.)

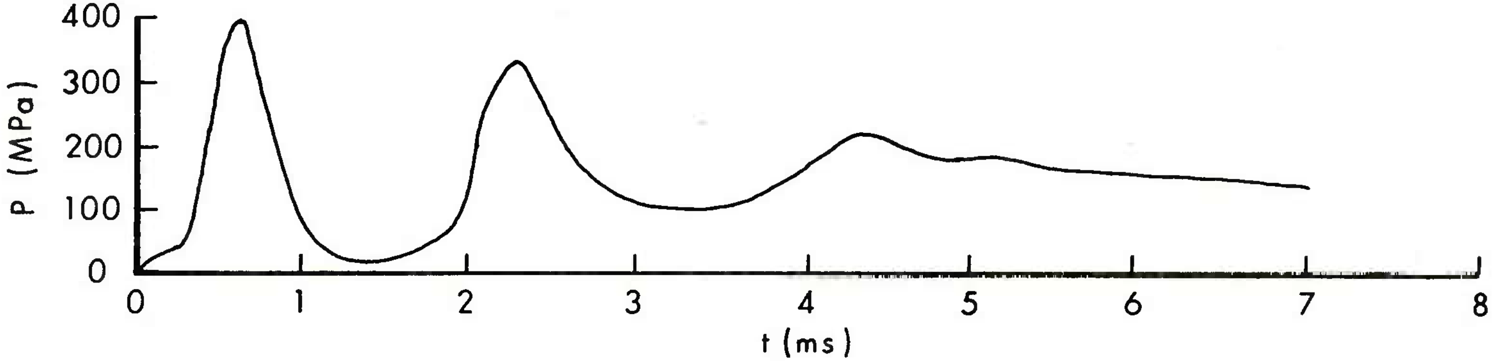


Figure 6A. Impact mode. Pressure vs time record of sample contained in a plastic cell. The sample consisted of LP with a 1000μℓ air space above it.

Figure 6B. Impact mode. Pressure vs time record of sample contained in a plastic cell. The sample consisted of water with a 1000μℓ air space above it.

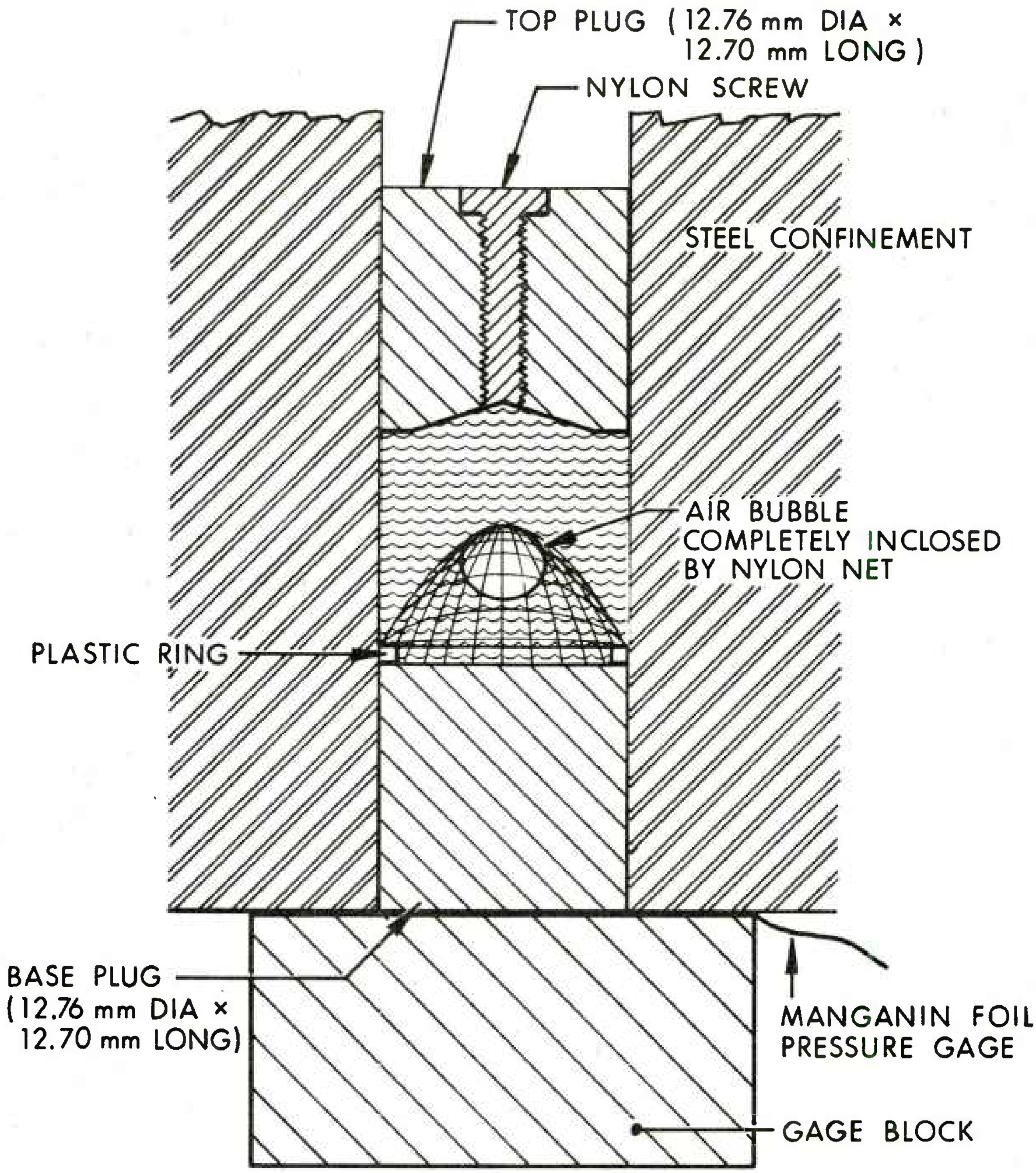


Figure 7. Sample sealed within steel confinement by plastic plugs.

completely inclosed the bubble, the confinement cylinder could be manipulated without dislodging the bubble. A 0.2mm thick Mylar piece and a thin layer of silicone sealant were then pressed onto the top plug to complete the assembly. A manganin foil pressure gage was cemented to a steel gage block and this block was then bolted to the confinement cylinder as shown in Figure 7.

1. RESULTS OBTAINED USING SEALING PLUGS.

The results of activator tests on LP with and without suspended bubbles are presented in Table III for contact mode and Table IV for impact mode of activator operation.

TABLE III CONTACT RESULTS-NO CELL

Shot No.	Bubble Vol. (μℓ)	Anticipated Inert Response: Peak Pressure (MPa)	Anticipated Inert Response: dP/dt (MPa/msec)	Measured Propellant Response: Peak Pressure (MPa)	Measured Propellant Response: dP/dt (MPa/msec)	Result*
10	neat	481	62	304	20	0
11	neat	170	26	170	26	0
12	1	170	26	130	25	0
13	5	170	26	455	131	2
14	10	170	26	387	62-109	2
15	10	481	62	636	68-202	2
16	100	481	62	667	202-690	2
17	100	170	26	>1350	682	2
18	100	481	62	698	528	2
19	100	481	62	558	667	2

The columns labled "anticipated inert response" contain values of the pressure and pressurization rate obtained either from firings where the propellant didn't react or where an inert substitute (water) was used. dP/dt is an eye fit average of the pressurization rate in the steady region following the initial pressure rise. It is indicated by a dashed line in the figures. Shot numbers 14, 15, and 16 showed an abrupt change to a higher pressurization rate.

* 0 = no reaction, LP recovered
1 = reaction, muffled bang
2 = reaction, loud bang

TABLE IV IMPACT RESULTS-NO CELL

Shot No.	Bubble Vol. (μℓ)	Anticipated Inert Response: Peak Pressure (MPa)	Anticipated Inert Response: dP/dt (MPa/msec)	Measured Propellant Response: Peak Pressure (MPa)	Measured Propellant Response: dP/dt (MPa/msec)	Result*
20	neat	306	681	306	681	1
21	neat	525	1060	257	750	0
22	neat	525	1060	398	927	1
23	neat	525	1060	-	-	0
24	10	306	681	340	932	2
25	10	525	1060	-	-	1
26	20	194	482	194	482	0
27	100	194	482	260	807	1
28	100	306	681	326	653	2
29	100	525	1060	522	1438	2
30	100	525	1060	483	1243	2
31	100	525	1060	503	1331	1
32	100	525	1060	514	1417	2
33	200	194	482	267	963	2
34	200	525	1060	542	1538	2
35	1000 (air gap)	-	-	600	4300	2

* 0 = no reaction, LP recovered
1 = reaction, muffled bang
2 = reaction, loud bang

2. DISCUSSION OF RESULTS OBTAINED USING SEALING PLUGS.

Unfortunately there appears to be no straightfoward interpretation of the data. One cause of this may be variations in the pressurization rates and peak pressure due to variation in the quality of the plastic seals from shot to shot. There is also the possibility that LP flowing at high velocity between plastic seals and steel activator components may react. However, in contrast to this possibility, we have several shots where the LP didn't react when it was squeezed out around the seals. One of these shots had a peak pressure of 257 MPa and a pressurization rate of 750 MPa/msec. Also, in four shots with neat propellant, there was either no reaction or a very mild reaction. We believe that the reactions tabulated in this report are due to rapid compression and heating of an air bubble within the LP and subsequent ignition of the LP by heat transfer.

One measure of the level of reaction is the measured pressurization rate, $\frac{dP}{dt}$, which is a function not only of the activator pressurization rate (input) but also of the increase in pressure due to LP reaction. Referring to Table III (contact mode, nominal rise time of 5 msec) it can be seen that the level of reaction increases with bubble volume. For an inert material such as water, the activator pressurization rate varies from 20 to 70 MPa/msec depending on breech pressurization rate and quality of the end caps which seal the liquid. The measured pressurization rate increases with bubble volume and in two cases, shots 14 and 15, there appears to be a transition from an inert response to reaction. The peak pressures generally increase with bubble volume although again the peak pressure is also a function of the plastic seals. The level of reaction is probably a function of peak pressure and input pressurization rate also but our data are not extensive enough to demonstrate this dependence.

In Table IV (impact mode, 0.5 msec nominal rise time) the pressurization rate depends on the free run of the main activator piston and the dynamics of the mechanical components of the activator, the LP sample and end seals. The columns labeled "anticipated inert response" contain values of the pressure and pressurization rate obtained either from firings where the propellant didn't react or where an inert substitute (water) was used. These values are only approximate and they are listed so that a qualitative comparison of reaction may be made with the adjacent column labeled "measures". It can be seen that neat LP gives evidence of reaction at the higher pressures and pressurization rates characteristic of the impact mode (shots 20 and 22). The rate of reaction (measured pressurization rate) appears to increase with bubble volume. One firing (shot 35) having a 1000μℓ air gap gave a measured pressurization rate of 4300 MPa/msec. In all these firings, the measured pressurization rate may be partially influenced by pressure release occurring at the plastic end seals. Some of the events labeled 1 in the result column would likely have reacted more violently if the propellant had remained better sealed by the end caps. Also, some of the incipient propellant reactions may have been quenched or moderated when the pressure on the

sample is reduced as the activator piston bounces after impact imparting a pressure pulse of approximately 1 msec duration. Referring to Table III for contact mode it can be seen that the results are either 0 or 2. The sustained pressure of the contact mode may be the significant factor in determining whether a mild reaction will continue to grow. Impact mode tests provide higher pressure and pressurization rates but they also introduce phenomena, piston rebound and restrike, which would not exist in proposed LP gun systems. For this reason, impact type tests should be interpreted with caution. The results of impact and contact modes of activator operation are shown in Figures 8 and 9 where measured pressurization rate $\frac{dP}{dt}$ is plotted against bubble volume. The contact mode results indicate that reaction didn't occur in neat propellant at a pressure of 304 MPa and a pressurization rate of 20 MPa/msec. Reaction did occur with a 5μℓ suspended bubble and not with a 1μℓ bubble in the 150 MPa range. Proposed ignition systems for an LP gun may produce 100-600 MPa at rates of 100-600 MPa/msec in the liquid propellant. There may be many thousands of air bubbles 0.1μℓ or less in volume or a single large ullage volume of several cubic centimeters depending on the particular system.

IV. PRESSURE-TIME HISTORIES OF LP SAMPLES

In the course of these experiments approximately 30 firings were made in which a manganin pressure gauge was positioned close to the LP sample in order to monitor the pressure-time history of the sample during compression. In this section we present and discuss several of these records.

A. CONTACT MODE PRESSURE RECORDS

Figure 10 is a pressure vs. time record of neat LP sealed in the confinement cylinder by plastic end plugs. The abscissa units are msec and ordinate units are MPa. A pressurization rate of 26.3 MPa/msec was obtained by an eye fit to the the linear portion of the slope. The peak pressure was 167 MPa and the rise time was about 5 msec. This is a typical non-reactive contact mode record obtained using a reduced powder charge in the activator breech (shot number 11 in Table III). Shot number 12 containing a 1μℓ air bubble gave a similar pressure-time record and will not be shown here.

Figure 11 is a pressure-time record of an LP sample with a 10μℓ suspended air bubble. The initial linear region of the slope is 68.2 MPa because a heavier powder charge was used in the activator breech. It can be seen that the pressurization rate abruptly changes to 202 MPa after 2 msec. This increase in pressurization rate we attribute to reaction occuring within the LP sample. At a pressure of 326 MPa there is a small decrease in pressure and then a continuation of the pressure rise up to a value of 636 MPa followed by a rapid drop-off in pressure.

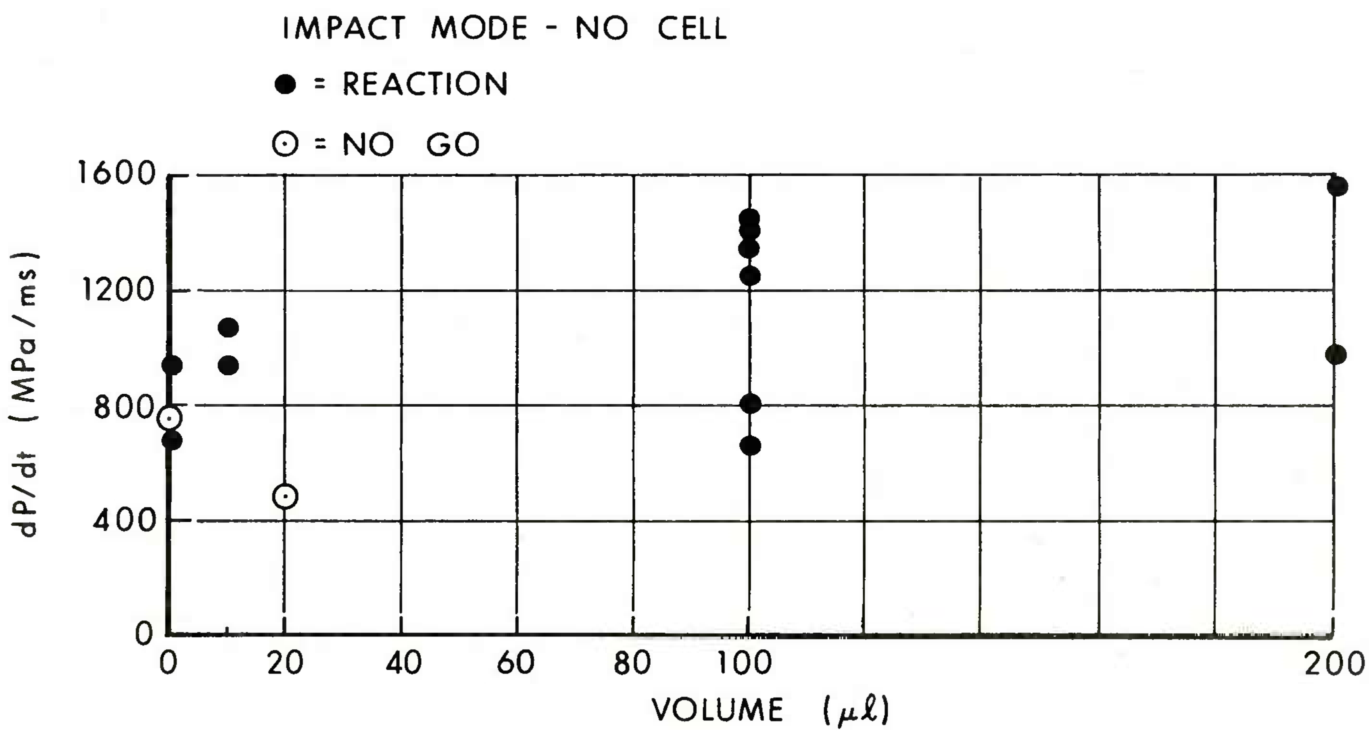


Figure 8. Measured pressurization rate vs bubble volume. Impact mode, no cell.

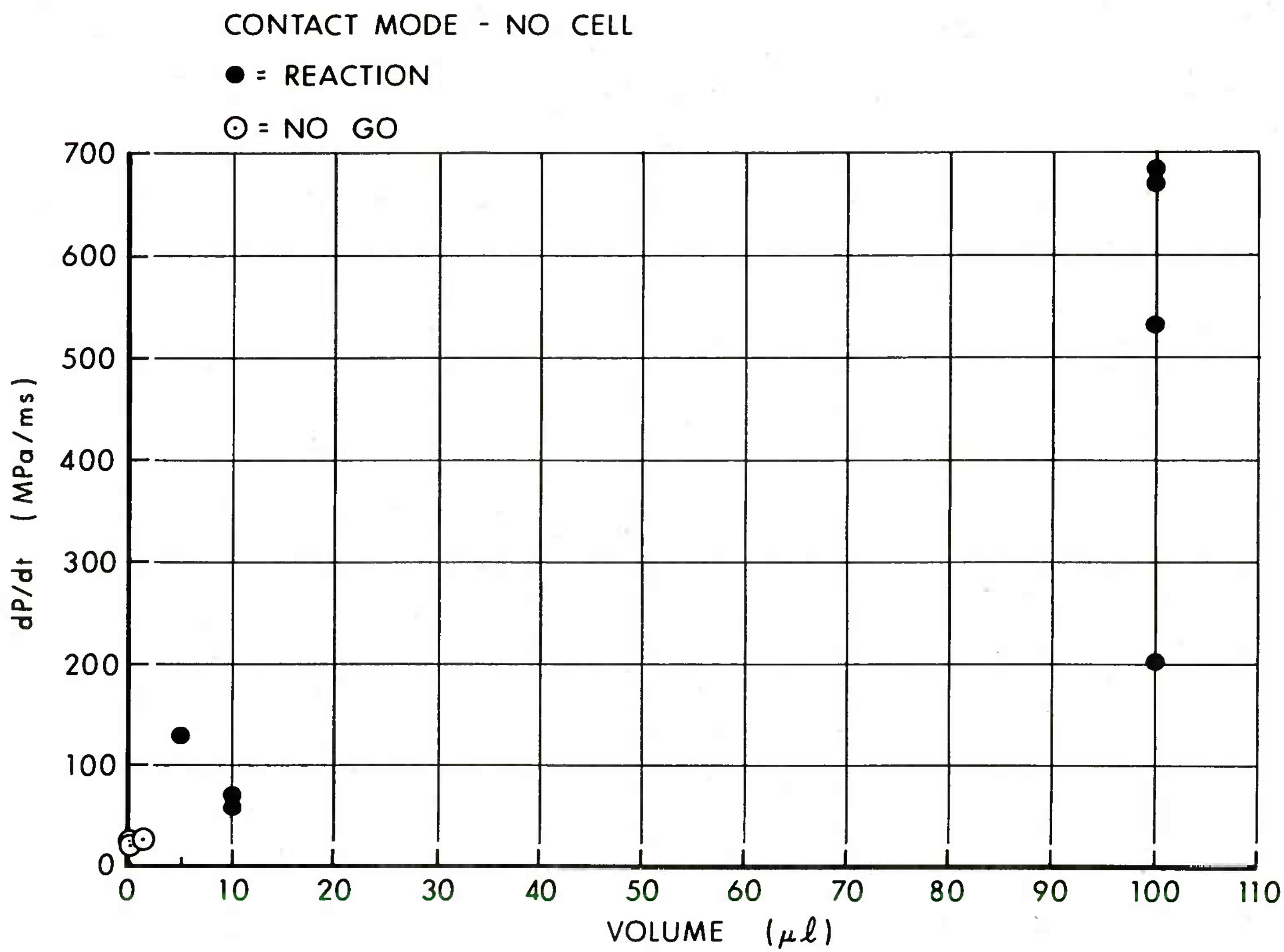


Figure 9. Measured pressurization rate vs bubble volume. Contact mode, no cell.

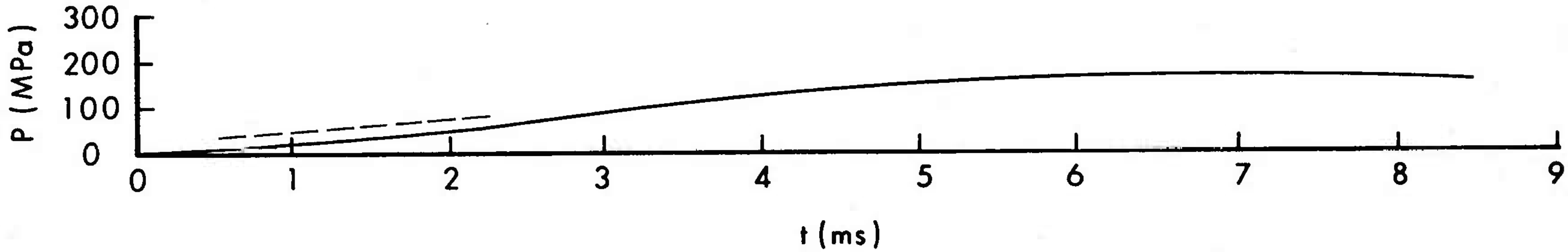


Figure 10. Pressure vs time record of neat LP. Contact mode, no cell. The LP didn't react.

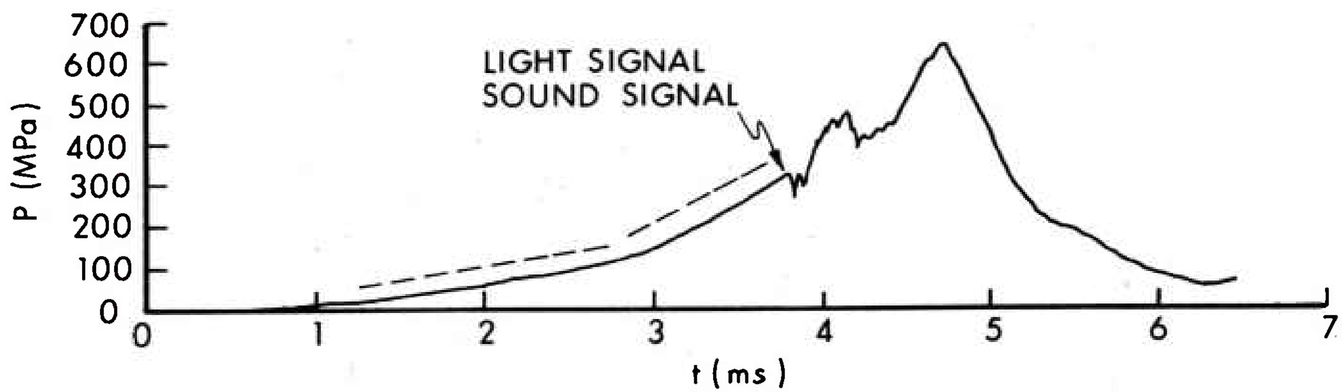


Figure 11. Pressure vs time record of LP containing a 10μℓ air bubble. Contact mode, no cell. The increase in slope indicates reaction.

Monitors placed near the sample gave light and sound signals coincident with the small decrease in pressure. We interpret this sequence to mean that the LP sample undergoing compression starts to react thereby increasing the internal pressure; the increased pressure causes some venting around the plastic plugs liberating high-pressure, incandescent reaction products. The venting is detected as a small drop in pressure on the pressure-time curve. As the LP continues to react the pressure reaches a peak value of 636 MPa before it is relieved by increased venting around the plugs. This is listed as shot number 15 in Table III.

Figure 12 is a pressure vs time record of an LP sample with a 100μℓ suspended air bubble. The linear portion of the slope is quite high at 202 MPa/msec indicating that reaction is underway. After approximately 2 msecs, the pressurization rate increases to 690 MPa/msec. In this firing the microphone detected low amplitude sound waves at t_1 which increased in amplitude at t_2. The light signal occurred at t_3, the same time at which the manganin gauge was destroyed. From this record, it appears that the gas generation rate is greater with a 100μℓ bubble than with a 10μℓ one. The pressurization rate abruptly changed to a higher rate but the peak pressure reached before venting occurred was about the same. The low amplitude sound waves may be a result of LP being squeezed past the end plugs at high velocity. This is listed as shot number 16 in Table III.

Figure 13 is a pressure vs time record of a plastic cell containing 1000μℓ of water with a 1000μℓ air gap above the water surface. The pressure initially increases in typical contact-mode manner but after approximately 1.5 msec the pressurization rate quickly changes to a high value of 277 MPa/msec. This is followed by a small drop in pressure and a gradual increase to a final value of 154 MPa. Although this is a contact mode firing the 1000μℓ of air above the water surface forms an air gap 7 mm long. This air gap allows the activator piston to accelerate, increase its momentum and transfer the momentum by impact when the air gap closes. The impact causes a higher pressurization rate which is followed by a decrease in pressure after rebound. The initial pressurization rate is moderated by the resistance of the cell walls which thicken as the cell is compressed.

Figure 14 is a pressure-time record of a plastic cell containing 1000μℓ of LP with 1000μℓ of air above the LP surface. When LP is used instead of water the maximum pressurization rate is 339 MPa/msec, approximetaly 20% higher than that of the water sample. The highest pressure reached is 205 MPa, 30% higher than that of the water sample. The condition of the recovered cell indicated that reaction had occurred. This is listed as shot number 5 in Table I.

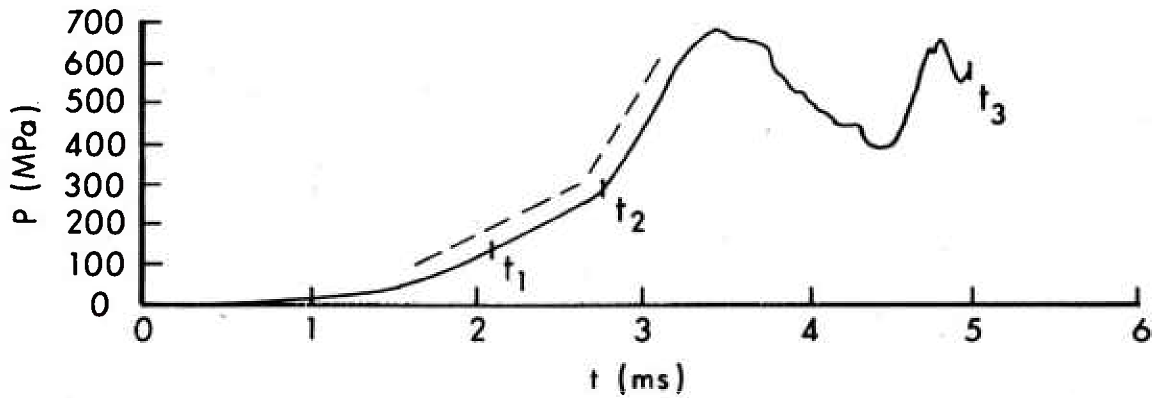


Figure 12. Pressure vs time record of LP containing a 100μℓ air bubble. Contact mode, no cell. Microphone detected noise signals originating at times t_1 and t_2. Light signal and gauge destruction occurred at t_3.

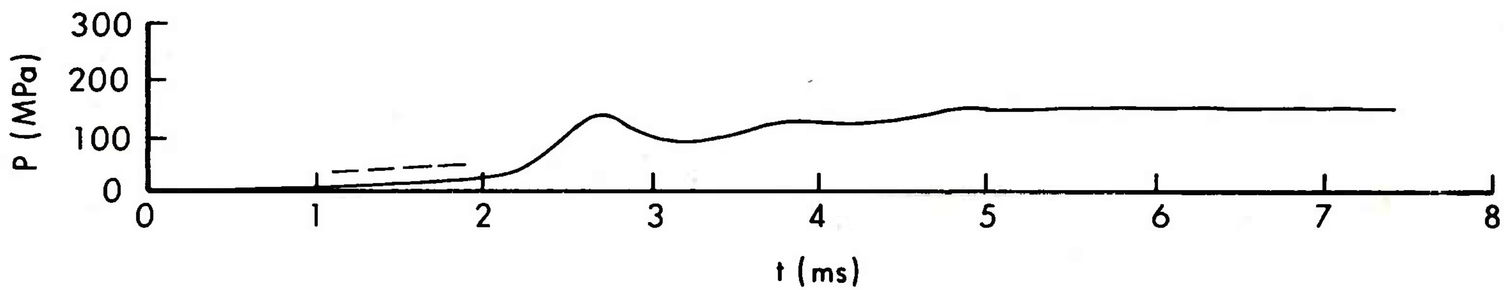


Figure 13. A pressure vs time record of a plastic cell containing $1000\mu\ell$ of water with $1000\mu\ell$ air gap above the water surface. Contact mode.

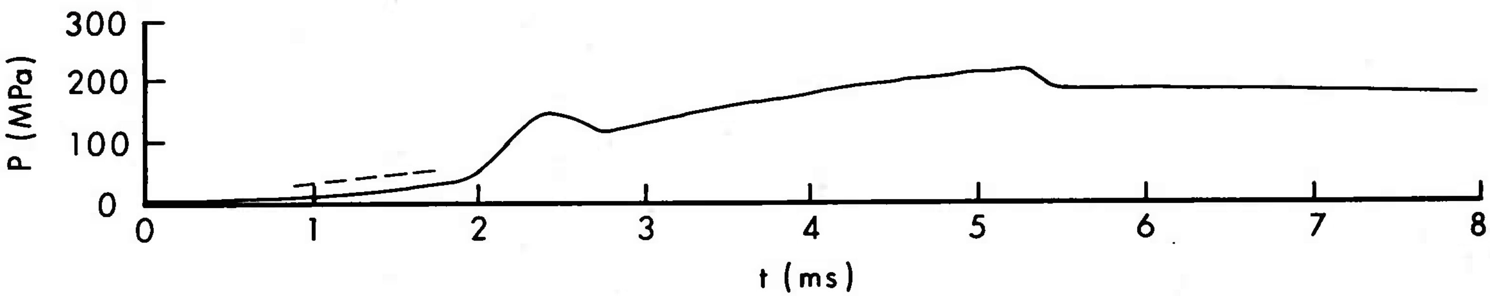


Figure 14. A pressure vs time record of a plastic cell containing 1000μℓ of LP with a 1000μℓ air gap above the surface. Contact mode.

B. IMPACT MODE PRESSURE RECORDS

Figure 15 shows an impact mode pressure vs. time record for neat LP. The pressurization rate is 750 MPa/msec and the peak pressure is 257 MPa. There was no reaction and LP was recovered around pistons and inside confinement cylinder after the shot. This is listed as shot number 21 in Table IV.

Another neat LP firing is shown in Figure 16. In this case, the pressurization rate is 681 MPa/msec and the initial peak pressure reaches 306 MPa and then decays in the typical impact mode manner as the piston rebounds. When the piston restrikes the pressure rises again and starts to fall off but then undergoes a pressure increase to 531 MPa at 6 msec after initial impact. This shot did not make a very loud noise but there was evidence of reaction on the recovered pieces. We believe the slightly higher initial peak pressure may have been sufficient to initiate reaction which accelerated upon restrike to the piston. This is shot number 20 in Table IV.

Figure 17 shows impact on LP containing a suspended 100$\mu\ell$ air bubble. After about 0.1 msec the initial pressurization rate changes to a higher rate of 1331 MPa/msec. The peak pressure reaches 503 MPa and decays as the piston rebounds. Seven milliseconds later the piston restrikes, the pressure increases to a higher peak value of 694 MPa and drops off as the piston rebounds again. This shot showed reaction but the noise was not very loud. It is listed as shot number 31 in Table IV.

Figure 18 is similar to Figure 17 but in this case the pressurization rate reaches 1417 MPa/msec and the peak pressure 514 MPa, both values slightly higher than previously. Restrike occurs after 5 msec and it is of interest to note that a vigorous reaction occurred resulting in a loud bang and destruction of the manganin pressure gauge. This is listed as shot number 32 in Table IV.

Figure 19 is another pressure record of a 100$\mu\ell$ air bubble suspended in LP. In this case the pressurization rate starts at 1438 MPa/msec indicating that vigorous reaction has started very early in the impact process. The pressure gauge broke after 0.8 msec. This shot gave a loud bang and the bore diameter increased to 13.59 mm from its original diameter of 12.70 mm. It is listed as shot number 29 in Table IV.

V. CONCLUSIONS

On the basis of the results presented we have reached the following conclusions:

1. A suspended air bubble makes LP more sensitive to pressure ignition.

2. The intensity of the reaction appears to increase with bubble size.

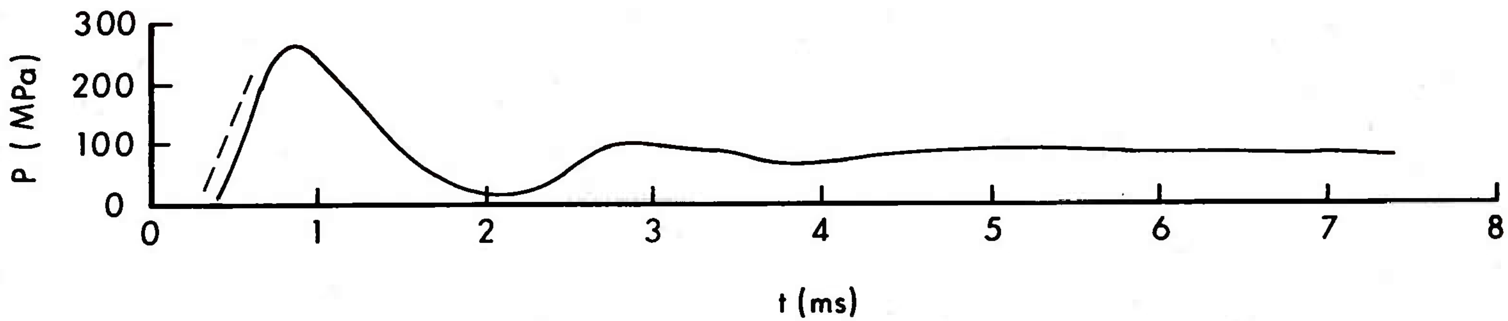


Figure 15. Pressure vs time record for neat LP. Impact mode, no cell. There was no reaction and LP was recovered on this shot.

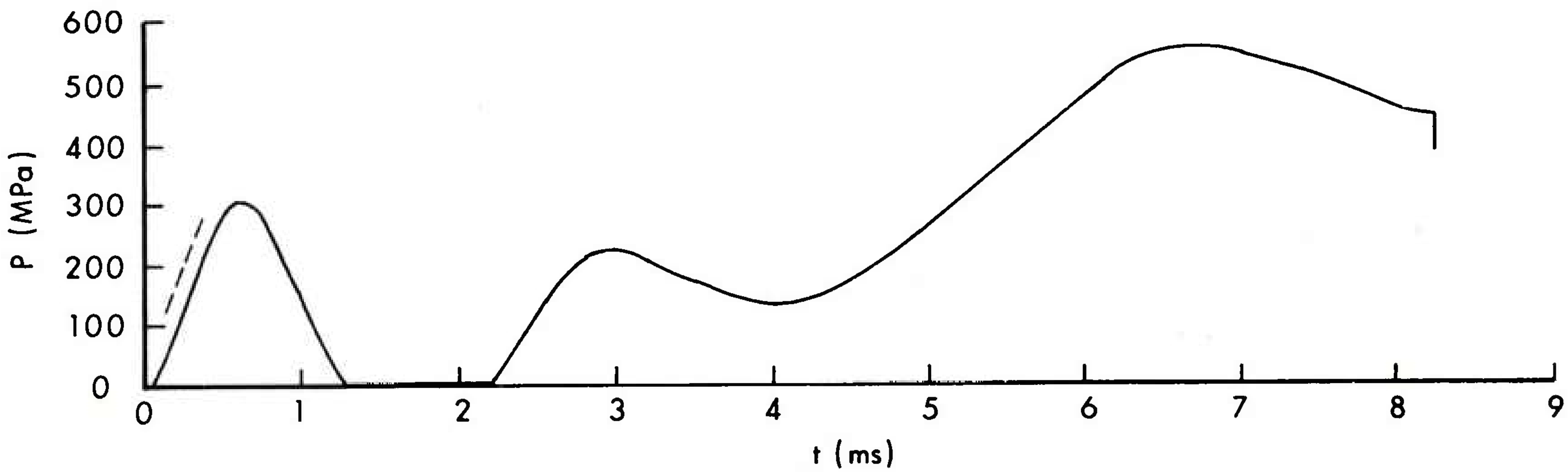


Figure 16. Pressure vs time record for neat LP. Impact mode, no cell. Reaction appears to start after restrike of the piston.

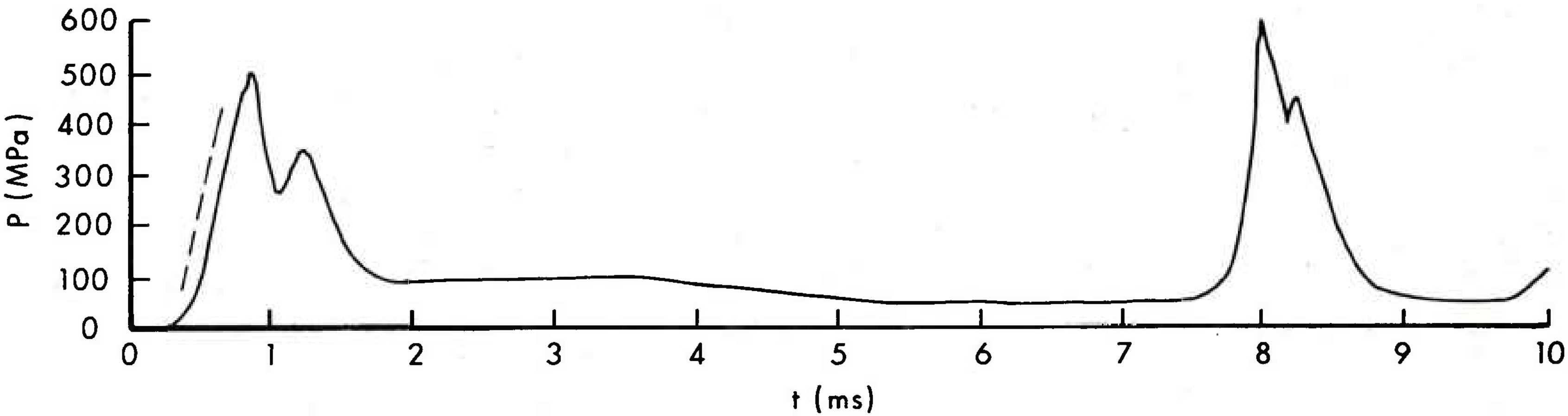


Figure 17. Pressure vs time record for LP containing a 100$\mu\ell$ air bubble. Impact mode, no cell. Reaction occurred but noise was not very loud.

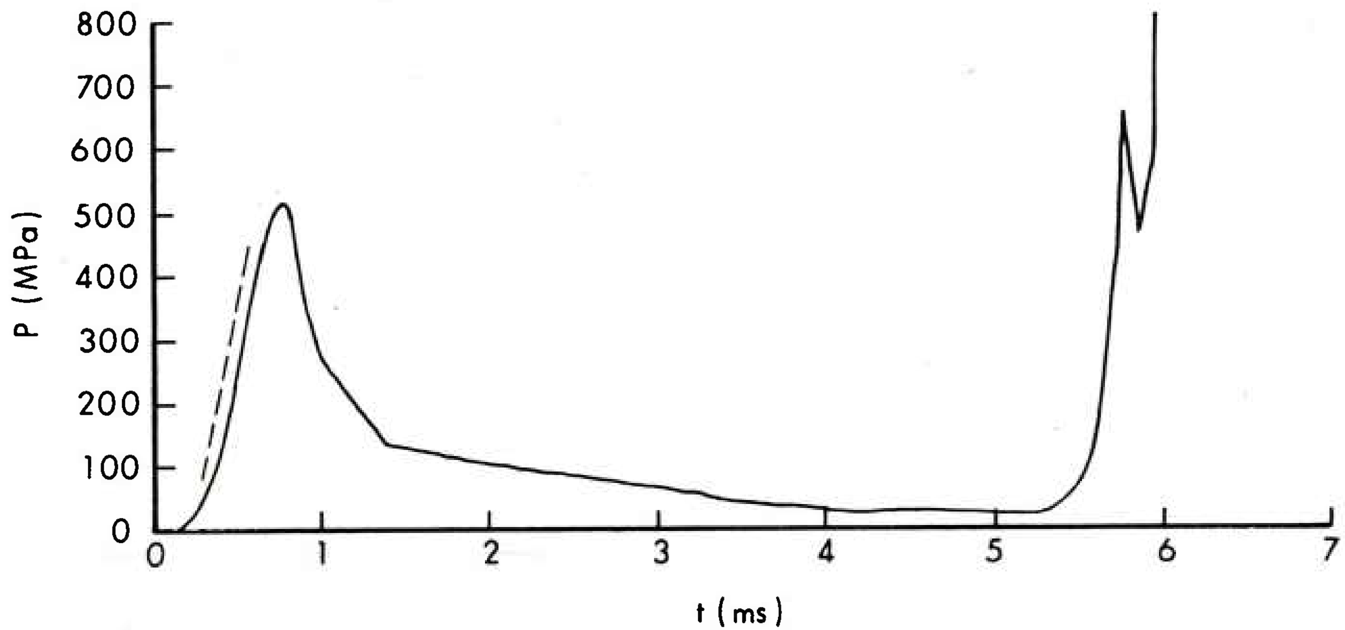


Figure 18. Pressure vs time record for LP containing a 100$\mu\ell$ air bubble. Impact mode, no cell. Vigorous reaction occurred resulting in a loud bang and destruction of the pressure gauge.

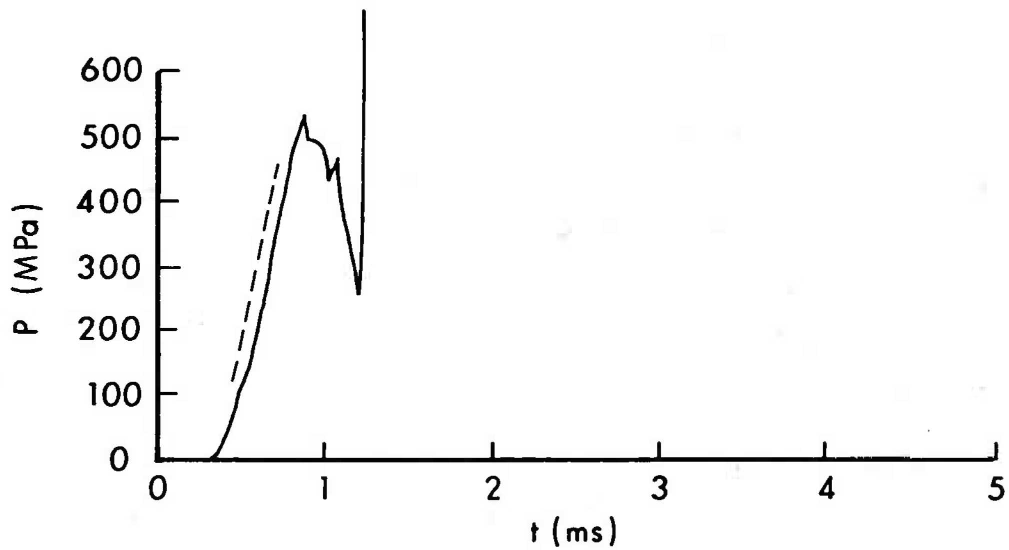


Figure 19. Pressure time record for LP containing a 100μℓ air bubble. Impact mode, no cell. The steep initial slope indicates that reaction is occurring early in the impact process. This shot produced a loud bang. The pressure gauge was destroyed at 0.8 msec after impact.

3. Higher pressurization rates caused ignition of neat propellant. However, this may be due to extrusion of the propellant around the pistons.

4. The impact mode of activator operation, although permitting higher pressures and pressurization rates than the contact mode, also gives more variability in the results.

VI. FINAL DISCUSSION

Conclusions 1 and 2 are based on all the tabulated data which show that the addition of a bubble to neat propellant sensitizes it to pressure ignition. Likewise there is a general trend for the intensity of the reaction to increase with bubble size. Conclusion 3 is arrived at by comparing the results of Tables III and IV for neat LP. It can be seen that the higher pressures and pressurization rates attainable in the impact mode lead to more ignitions. Conclusion 4 follows from the variability in the results and the nature of the impact process where pressure decrease upon rebound would tend to moderate incipient reaction or perhaps quench it completely. The rebound could also cavitate the liquid due to expansion as suggested in Figure 16. On the other hand, restrike of the piston may cause ignition around a previously heated air bubble or accelerate reaction already underway. Since the impact mode of activator operation introduces mechanisms (rebound and restrike) which are not found in typical gun firings, these impact results should be interpreted with caution. Perturbation due to the restrike mechanism is graphically illustrated by comparing Figures 17 and 18 where, upon restrike, one sample transits to a violent reaction and the other does not.

If there is to be a continuation of this work in the future, it is recommended that additional contact mode firings be made to better define the relationship between bubble volume, pressure, pressurization rate, and propellant ignition. Efforts should also be made to prevent propellant flow around activator pistons in order to eliminate the possibility of propellant ignition by friction and viscous heating. Also, an attempt should be made to measure the pressure directly in the LP sample.

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